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The International Monitoring System Infrasound Network: current status and existing challenges.

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The CTBT International Monitoring System (IMS) Network: Infrasound component

The IMS Infrasound Network is facing two interconnected challenges:

1. **Reaching the target of 100% operational infrasound facilities**

…while…

2. **Sustaining the existing ones at different levels of their lifecycle**

To address both challenges, the IMS Engineering and Development (IMS/ED) Infrasound Team develops projects focused on installations/sustainment and actions aiming at ensuring continued compliance with the IMS Operational Manual requirements on:

- **Data availability**
- **Data surety**
- **Data quality**

Infrasound – 53 of 60
88%

Challenges in sustainment of the the IMS Infrasound Network

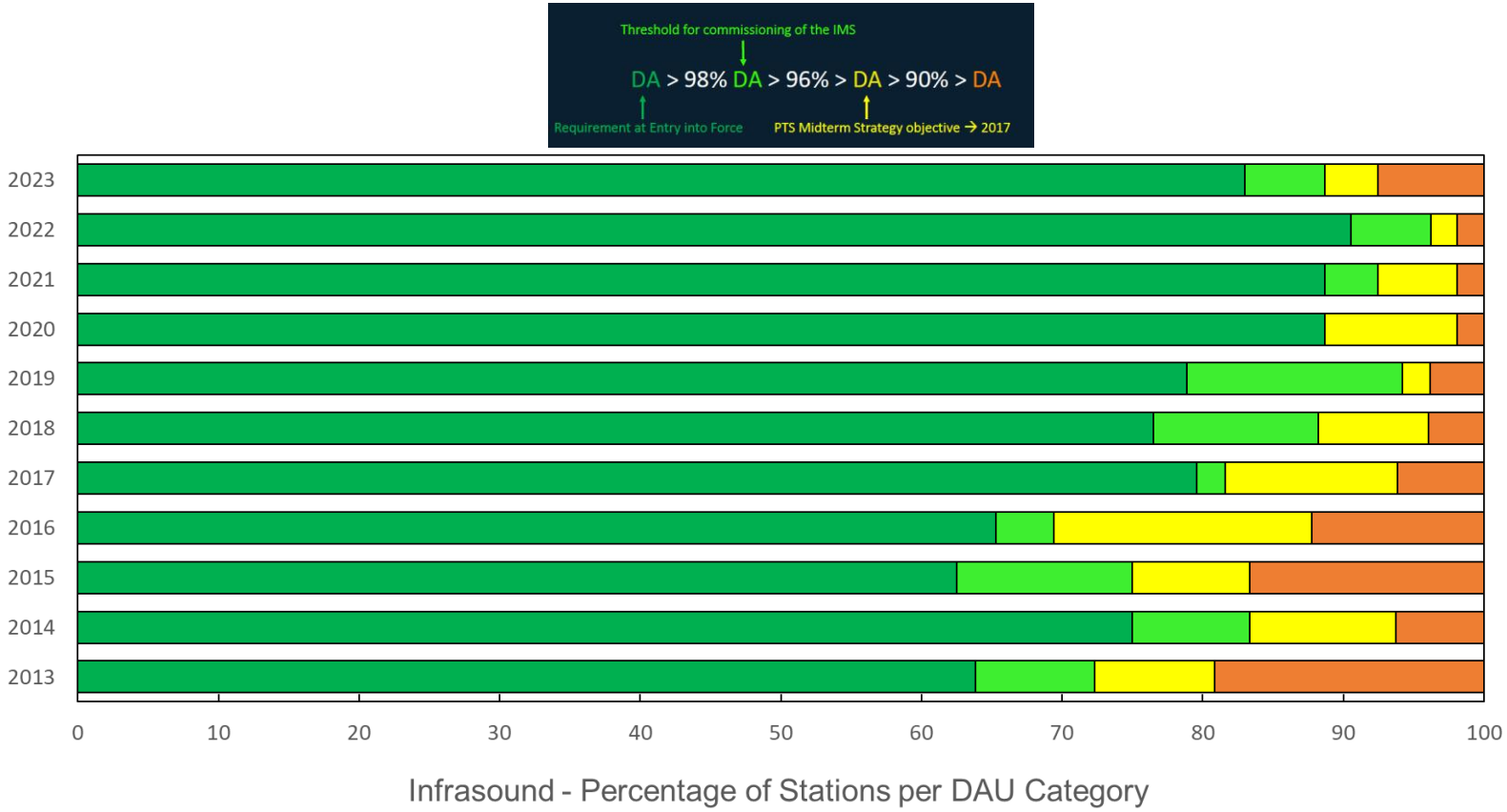
Open questions

- How to maintain the IMS infrasound facilities fully operational?
- How to mitigate loss of Mission Capability and of Data Availability?
- How to integrate technological solutions/advancements to enhance robustness and resilience to data loss and/or Data Quality deterioration?
- How to enhance Data Availability, Data Quality, Data Surety?
- How can Quality Assurance help sustain the IMS network?

Factors triggering recapitalizations and upgrades

- Systematic technical failures or long-term issues causing:
  - Loss of Mission Capability
  - Data Availability not meeting requirements
  - Data Quality issues (e.g. noisy data)
- Station not meeting minimum technical requirements (e.g. calibration, authentication)
- Equipment deterioration (e.g. corrosion) from adverse environmental conditions
- End of life of equipment
- Lack of spare components
- Obsolescence occurrence (CTBT/PTS/INF.889)
- Decreased system/equipment reliability (CTBT/PTS/INF.889)
- Increasing operations and support costs (CTBT/PTS/INF.889)

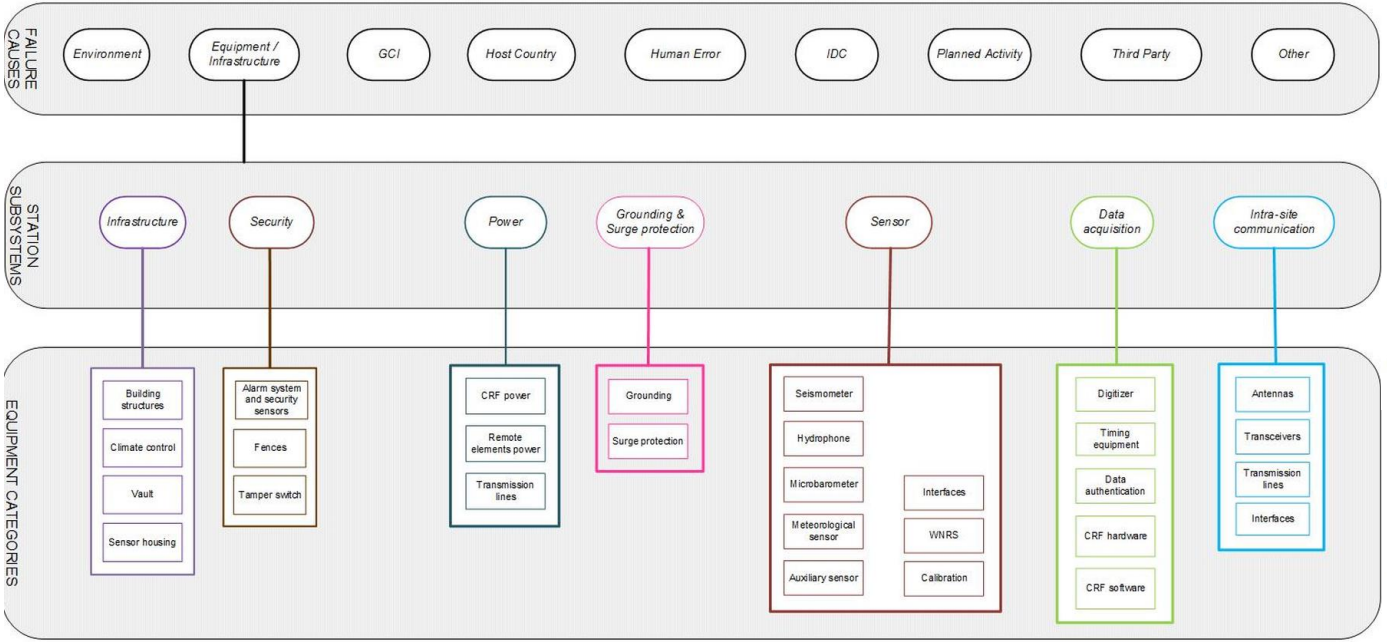
Factors triggering recapitalizations and upgrades

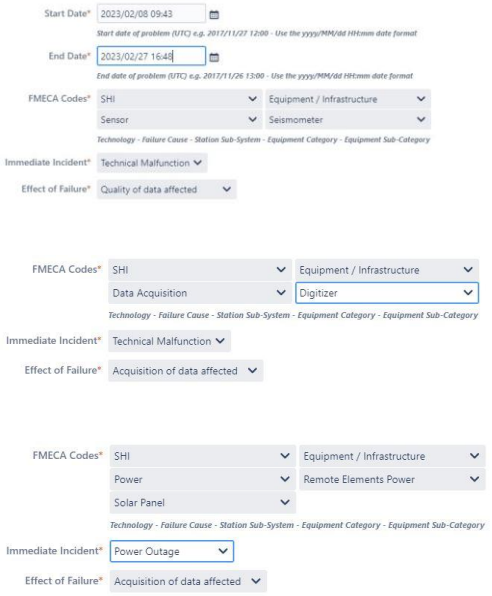


Failure Analysis
Learning from the far and near past to plan engineering solutions

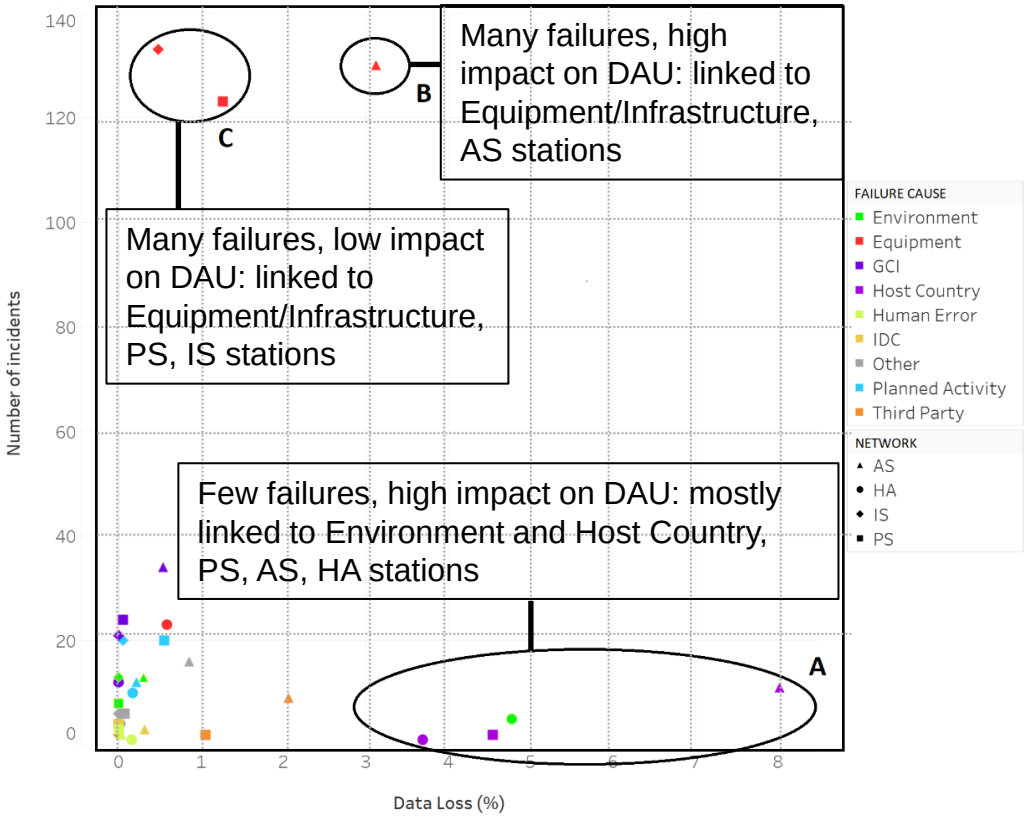
IMS Reporting System (IRS): Failure Mode, Effects and Criticality (FMECA) analysis

Categorization of failure causes, station components/subsystems and type of equipment to help identify major sources of Data Loss (from Failure Analysis, ECS/WGB-60/PTS/11)

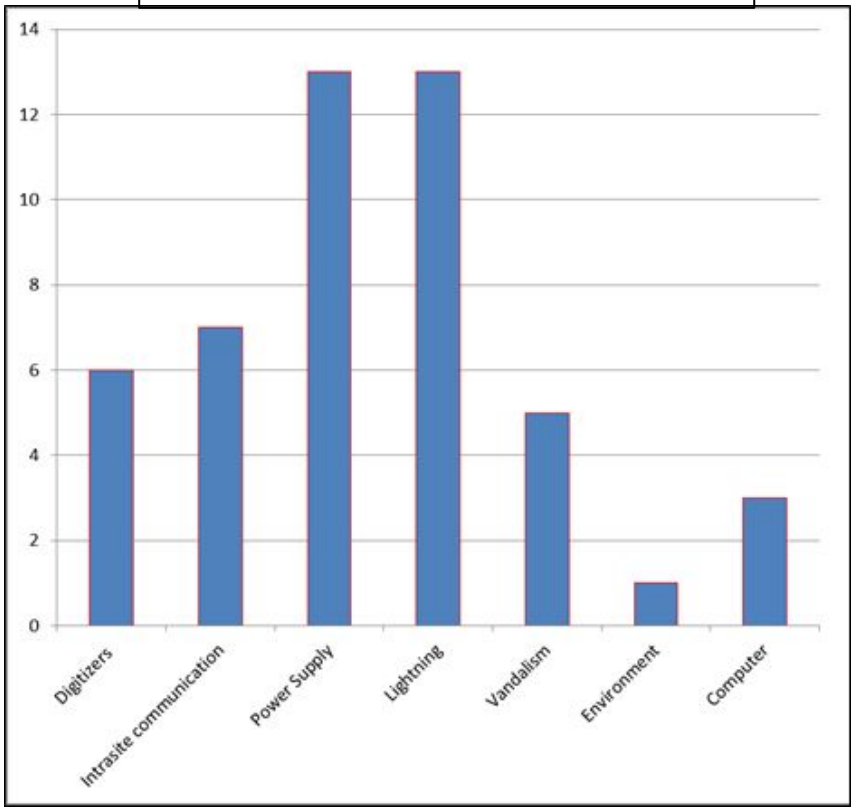




Failure Analysis: main causes of Data Loss impacting Data Availability



Major equipment/infrastructure failures



Infrasound Stations: Recapitalizations

Initial status:

- **Heavy rains** caused over several years damages due to **flooding**.
- **All MB2005 damaged** since located in underground cases to mitigate seismic response generated by winds blowing on vaults above ground.
- **Wind Noise Reducing System (WNRS) not yet standardized** (36m with resonance suppressors)

IS11, Cape Verde: 2023

IS11, Cape Verde

Actions

- **Replacement of sensors: Hyperion** IFSN-5402-00100-A-PTS.
- **All vaults adapted with reference inlet port** for the forthcoming implementation of calibration capability.
- **Replacement of Digitizers: 6-channels** digitizers in view of calibration capability implementation

Quanterra Q330M+
GNSS antenna
Spyrus authenticator

- **Replacement of meteorological station**: from analog to digital.
- **Replacement of WNRS: 18-m** diameter standardized.
- **Replacement of** Standard Station Interface (**SSI**) **machines**.
- Preliminary testing of potential backup GSM network

Forthcoming: **installation of calibration capability**

IS11, Cape Verde

Infrasound Stations: Recapitalizations

IS19, Djibouti, 2023

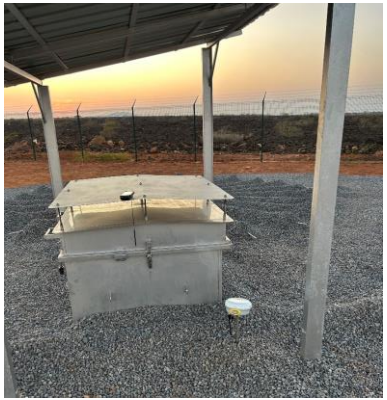
Initial status:

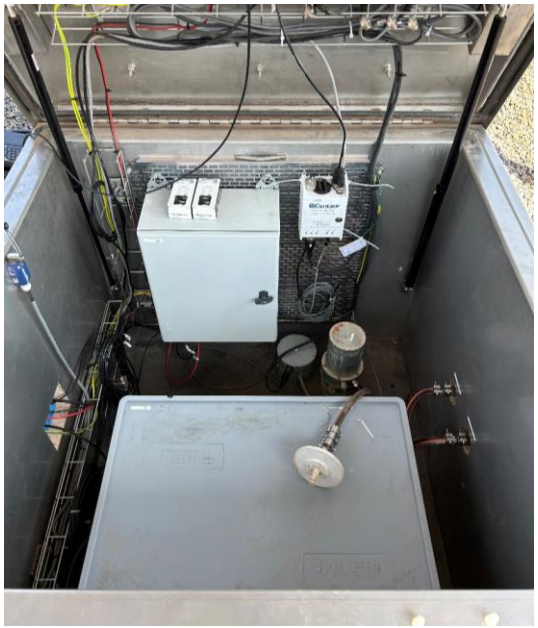
- Equipment close to end of lifecycle and affected by obsolescence.
- Sites L4 and L8 heavily damaged by flash flooding.
- Need for access roads repairs.
- Wind Noise Reducing System (WNRS) not yet standardized (36m with resonance suppressors)

IS19, Djibouti

Actions in 2023:

- **Replacement of Station vaults, Power, Communications equipment.**
- **Sensors: Hyperion** IFSN-5402-00100-A-PTS
- **Digitizers: Centaur** CTR4-6A-S.
- **Implementation of calibration capability: MB2005**





Infrasound Stations: Recapitalizations

IS49, Tristan da Cunha, United Kingdom: 2019-2023

Initial status:

- **Equipment close to end of lifecycle and affected by obsolescence and remoteness of the location required recapitalization.**
- **Wind Noise Reducing System upgraded in 2019.**

Actions in 2023:

- **Replacement of Station vaults, Power, Communications equipment.**
- **Sensors: Hyperion** IFSN-5402-00100-A-PTS
- **Digitizers: Centaur** CTR4-6A-S**.**
- **Implementation of calibration capability**

Infrasound Stations: Recapitalizations

IS40, Keravat, Papua New Guinea, 2024

Initial status:

- Equipment affected by multiple failures and remoteness of the location required recapitalization.
- Frequent power outages and communication problems.

Actions :

- Installation of new vaults
- New WNRS
- Installation of new microbarometers + digitizers
- CRF computers upgrade
- Troubleshooting of power system problems Installation of new WNRS
- Implementation of calibration capability

IS40, Keravat, Papua New Guinea, 2024

Forthcoming: installation of sensors for calibration capability

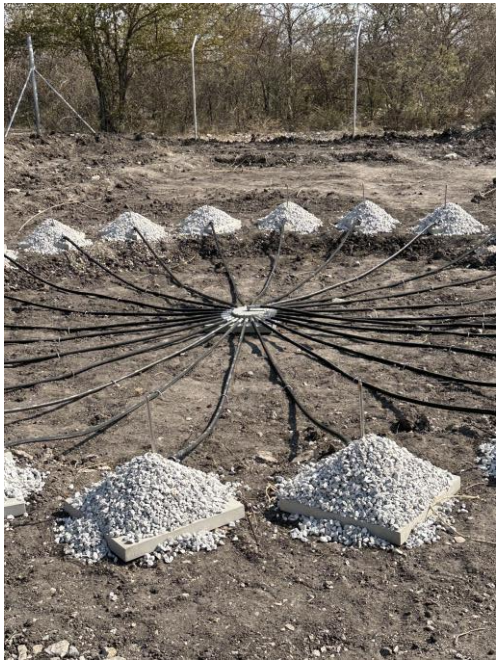
Infrasound Stations: Recapitalizations

IS35, Tsumeb, Namibia, 2024

- Recapitalization process started in 2019 with the replacement of digitizers.
- Works in 2023 included installation of AC cables and fiber optic cables between the array elements and the CRF.

Actions in 2024:

- Completed refurbishment of power supply and communication systems.
- Replacement of WNRS
- Installation of reference sensors to implement calibration capabilities



Increase of the number of array elements:
a strategy to enhance robustness and Mission Capability and improve detection capability

Infrasound Stations recapitalizations: Ongoing/Forthcoming actions

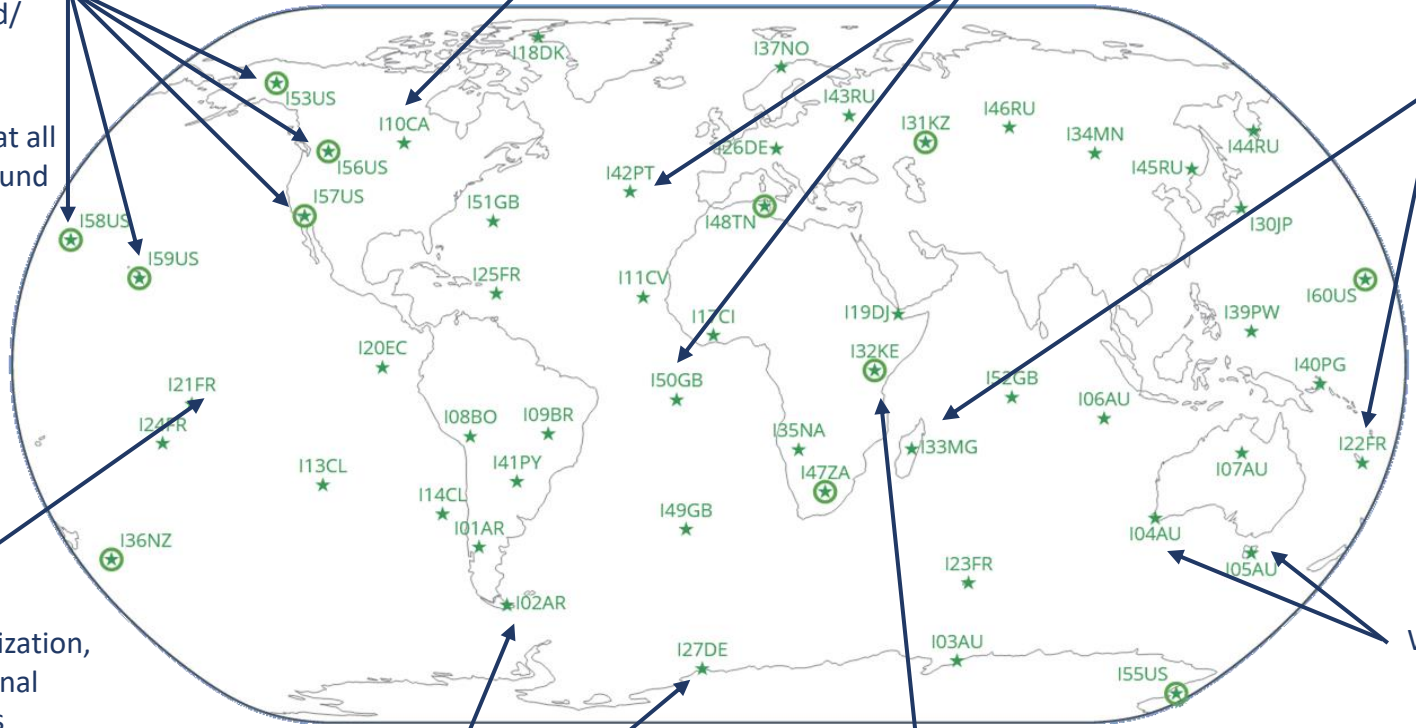
Sensor upgrade (2019 to 2021), Completed/

Ongoing digitizer upgrades at all US infrasound stations

Planned 4 additional elements, WNRS, sensor

Planned recapitalization (sensor, digitizer)

Planned recapitalization 4 additional elements



Planned recapitalization, 4 additional elements

Recapitalization

Recapitalization

Planned power upgrade

WNRS upgrade

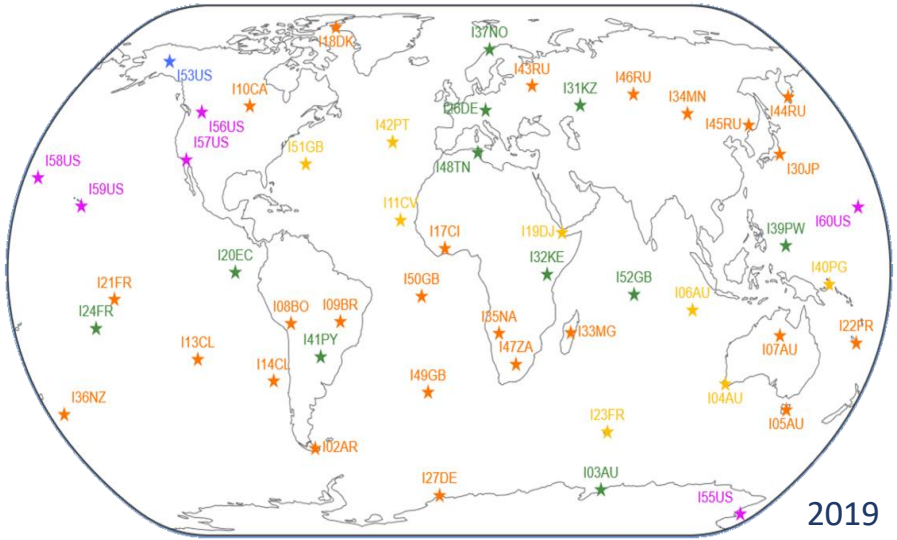
Maintaining a large network: use homogeneous equipment to facilitate logistics or differentiate?

Differentiating equipment in geographical areas helps minimize risk of large-scale/regional Mission Capability (MC) failures and consequent degradation of Network Detection Capability

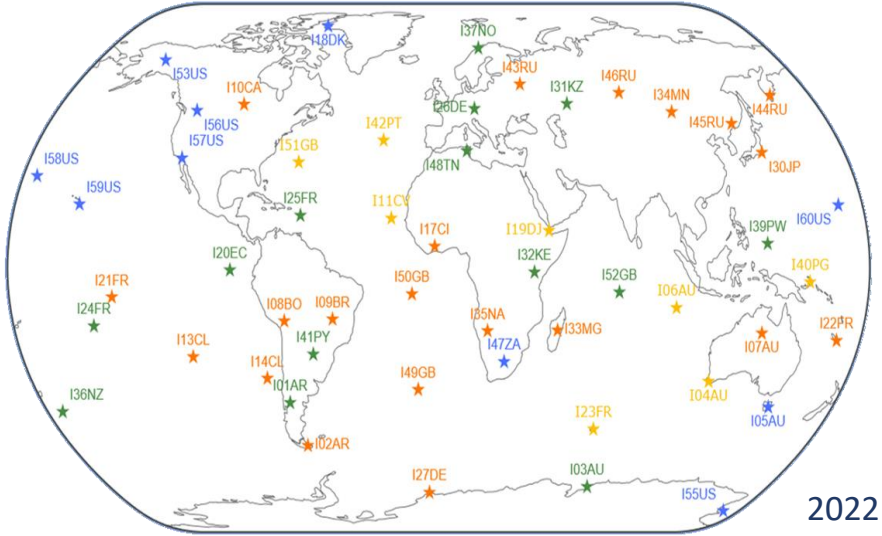
Differentiating equipment: the infrasound case

Many sensors at IMS stations are **reaching the end of life**. **How to address the replacement**?

Target: distribution of sensor models across the network. Example of infrasound sensors



2019



2022

MB2000 (25 → 21)

MB2005 (8)

Chaparral 50A (6 → 0)

Seismowave MB3a (11 → 14)

Hyperion 5313A (1 → 10)

Continuous progress in refinements of the Standard Station Interface (SSI) software helps stabilize data flow from Station to International Data Centre

Looking forward

How reliable are the measurement devices we are going to deploy at IMS infrasound facilities?

Quality Assurance, Type Approval Process and Metrology

Quality Assurance: Calibration and Type Approval process

Type approval for infrasound sensors

Evaluation of sensors to verify compliance with IMS Operational Manual (OM) minimum requirements.

Environmental qualification testing: transportation, temperature testing, electromagnetic vulnerability (EMV) and electric surge protection testing, etc.)

Integration testing with main digitizers used in the IMS network.

Device acceptance to ensure compliance with IMS OM and manufacturer requirements of each purchased sensor.

Work in close cooperation with specialized laboratories and equipment providers to enhance robustness of equipment deployed in the field in multiple environmental conditions

Calibration by comparison for infrasound sensors

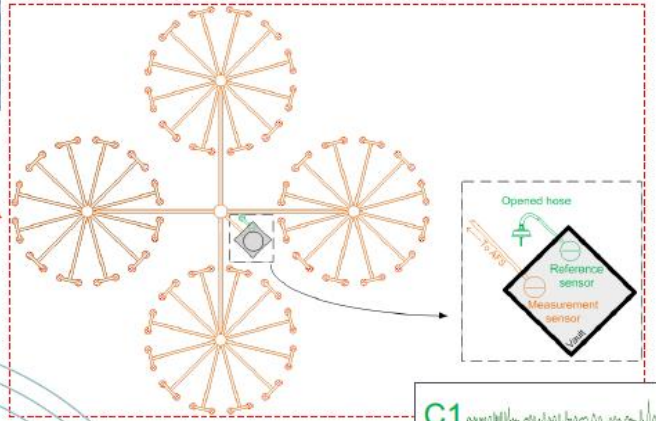
Scheduled Calibration **process supported by software** (CalxPy) for IS stations equipped with calibration capabilities: calibration is **continuous**

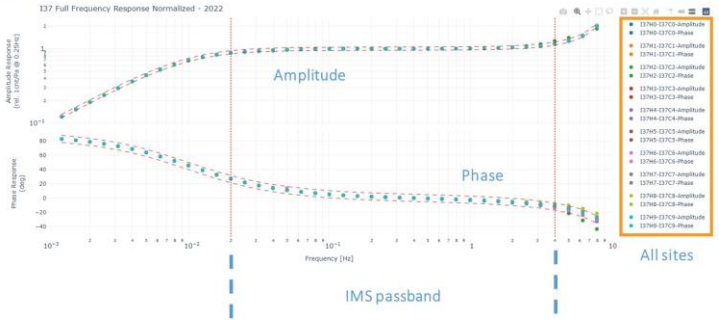
4 phases

Verification that calibration is possible (via CalxPy, IRS)	PLANNING
Automatic results computation (via CalxPy)	IMPLEMENTATION
Results reviewed at the PTS (via CalxPy) Troubleshooting/maintenance initiated if applicable (via IRS)	REVIEW
Validated calibration results prepared for being shared with Authorized Users (CalxPy). Update of computed sensitivities in the digitizers (followed via IRS, data frames)	PUBLICATION

CalxPy

IS26 - Germany





Tracing issues through calibration by comparison: an example

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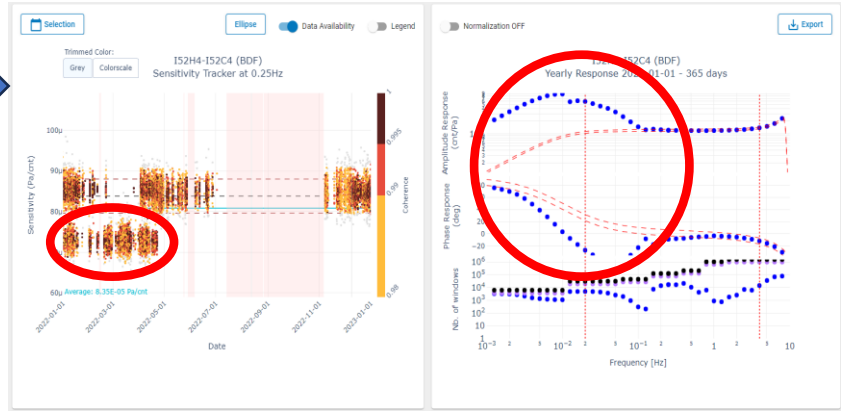
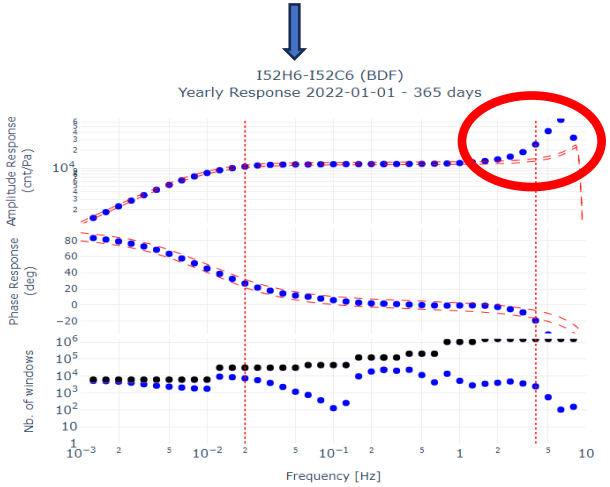
2 issues identified and fixed:

- ✓ inverted connection between operational & reference channels at the digitizer level following maintenance activity
- ✓ **reference sensor Data Quality issues**



1 issue identified: flooding



Calibration by comparison allows a robust identification of issues based on the acquisition of a large dataset across the entire year, including potential effects linked to seasonal variations.

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